Validating the Concept of the Next Generation Greenhouse Cultivation: an Experiment with Tomato

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Abstract

For a more sustainable greenhouse horticulture, a considerable reduction of the use of energy is needed, but trade-offs with production and quality are not acceptable. The Next Generation Greenhouse Cultivation is a concept for energy saving, consisting of modules that can be implemented step by step into practice. Use of highly insulating screens, forced ventilation and the integration capacity of a crop are the main components of the concept. To validate the results of a desk study an experiment in a greenhouse of 1000 m^2 equipped according to the concept was performed. The experiment proved that it was possible to produce 69 kg.m^{-2} truss tomatoes with an energy demand for heating of 750 MJ.m^{-2}. In the Netherlands, this concept is currently applied in practical tomato cultivation and in several other crops.

INTRODUCTION

The need for sustainable production and energy saving in greenhouse horticulture is indisputable (Montero et al., 2011; Dieleman and Hemming, 2011). Recently, model studies were used to evaluate new ways for energy saving (Elings et al., 2005; Campen, 2008). However, these studies did not result in an integrated approach for commercial cultivation with a low energy requirement. Semi-closed greenhouse were found to be an energy-saving greenhouse concept (Opdam et al., 2005). However, application on a commercial scale faced serious problems in climate and climate regulation for application (Gieling et al., 2011). To fulfil the need to reduce the energy demand of greenhouse production, a new concept: The Next Generation Cultivation for tomato was developed based on model simulations, knowledge from on-going research and expert knowledge (De Gelder et al., 2012). The whole concept of the Next Generation Cultivation exists of 6 elements: screens for insulation, forced ventilation, temperature integration, adjustment of the production plan, strategic CO_2 supply and the use cooling, heat pump and aquifer. This concept is based on high insulation, forced ventilation and optimal use of the integration capacity of the crop. Experience shows that growers will not apply a new concept, unless it is proven to be realistic. Therefore, a validation experiment was performed to test the feasibility of the new concept. Because the use of cooling, heat pump and aquifer needs high investments and does not influence the energy demand for temperature control, this element was not used in the validation experiment. A question to be answered is whether the information developed with models is valid for commercial greenhouses.

MATERIALS AND METHODS

The experiment was done with a tomato crop in a Venlo type greenhouse of 1000 m^2 in Bleiswijk, the Netherlands. Growers and a crop consultant were involved to ensure optimal comparison with reference growers and to promote knowledge transfer to growers and acceptance of the approach in practice.

Greenhouse specifications were comparable with commercial greenhouses:

Greenhouse type	: Venlo cover 2 * 4.8 m
Glass and slope of the cover	: 91% transmission and 22% slope
Gable post height	: 6.68 m

Ventilation	: 2 ventilation windows per 5 m at both sides
Heating	: Pipe-rail 6 * 2 pipes of 51 mm ø next to each other
	: Growth pipe 6 * 2 pipes of 35 mm ø above each other
CO_2 supply	: Supply capacity of 18 g.m^{-2}.h^{-1} (external industrial source)
Climate computer	: Priva Integro
Cropping system	: V-system, hanging gutter, 50 cm above the floor
Gutter distance	: 1.60 m – Gutter type Meteor
Crop wire	: 4.5 m above the floor
Substrate type	: Grotop – Master - size 120×19.5×7.5 cm (length×width× height)
Water supply	: 1 dripper per plant with a supply capacity of 2 L.h^{-1}

To achieve maximal insulation, the screening installation was equipped with two screens, which has opposite directions.

Upper screen	: XLS 18 Firebreak
Lower screen	: XLS 10 Ultra Revolux

In the front, rolling side-wall screens were mounted, that could be controlled separately. For the forced ventilation ducts were mounted under each gutter with openings of 0.8 cm in the horizontal plane each 26 cm to blow the air in with a maximal ventilation capacity of 5 m^3.m^{-2}.h^{-1}. The air treatment unit to which the ducts were mounted was equipped with a heat exchanger to heat the air blown to the desired greenhouse air temperature.

The tomato cultivar Cappricia was grafted on the rootstock Maxifort, sown on 21 November and planted on 14 January 2009. Planting density was 1.9 plants.m^{-2}. From 5 February onwards, one additional stem per plant was maintained, resulting in a stem density of 3.8 stems.m^{-2}. Fruit harvests started on 17 March, final harvest was on 25 November. At the start of the experiment, prognoses of production and energy use were made, based on model simulations and expert knowledge of a crop consultant, assuming an average year. Expected production and energy demand are shown in Figures 1 and 2. Realised crop production and energy use were evaluated with the crop growth model INTKAM (Marcelis et al., 2000) and the greenhouse climate model KASPRO (De Zwart, 1996). The weather data (Fig. 3) and realised climate were used as input for this evaluation.

Growers and a crop consultant visited the trial once a week to see crop development and to discuss the climate strategy for the next week. Information on the progress of the experiment was available on the internet website www.energiek2020.nu on a weekly basis.

RESULTS

Total tomato production at the end of the season was 69 kg.m^{-2} (Fig. 1) with an energy input van 750 MJ.m^{-2} for heating (Fig. 2). Start of the production was delayed with about one week. The crop growth model INTKAM (Marcelis et al., 2000) calculated a production of 67.2 kg.m^{-2} based on the realized climate. This matches well with the observed values.

With the greenhouse climate model KASPRO (De Zwart, 1996) the simulated energy use was calculated to be 700 MJ.m^{-2}, whereas in the experiment 750 MJ m^{-2} was used. The model overestimated the heat demand in the beginning of cultivation. In autumn the model underestimated the heat demand, but in general the energy simulation fitted well with the observations. Energy input followed approximately the energy demand that was estimated before the cultivation. Until the end of February relative humidity was below 90 %, which is no problem in the greenhouse. Transpiration of the young crop was still low and due to low outside temperature the condensation on the roof was sufficient to maintain a low relative humidity. End of March, beginning of April energy input was very low, since a high humidity was accepted because the growers wanted to see the level of vapour deficit that could be accepted (Vapour Deficit (VD) <1.2 g/m^3). The high relative humidity lead to a severe problem with Botrytis (data not shown). To control this disease more energy for dehumidification was used beginning of May.

The energy screen (LS-XLS 10 Ultra Revolux) was used during 2389 h and the highly insulating screen (LS-XLS 18 Firebreak) during 1640 h (Fig. 4). The highly insulating screen was thereby used during more hours than a standard energy screen in practice (data not shown). The diurnal temperature was regulated based on crop development, fruit load and daily radiation sum. In the course of the cultivation, the base temperature was lowered from 17.3°C in January-March to 15.5°C in October (Fig. 5). In the beginning of the cultivation, fruit load of the crop was low. The 24 h temperature was kept high in relation to the radiation sum. At the end of the cultivation, 24 h temperatures were lowered to reduce the development rate to obtain maximal fresh weights of the fruits.

CO_2 was applied from an external source and was therefore always available in this experiment, which may have had a favourable effect on the production level.

Humidity can be controlled with forced ventilation, if the absolute humidity outside is lower than the absolute humidity in the greenhouse. The example of climate control shown in Figure 6 shows that as soon as the forced ventilation started, the VD under a closed screen became higher.

DISCUSSION: LIMITATIONS AND APPLICATIONS

A concept for a new growing system for tomato with a great reduction of energy demand was developed with the knowledge of experts and the application of models (De Gelder et al., 2012). This experiment was carried out to validate this concept. The first year of experimentation showed that applying the first components of the energy friendly concept is feasible.

The model calculation for the Next Generation Cultivation approach for growing tomato resulted in an energy demand of 875 $MJ.m^{-2}$ (De Gelder et al., 2012). The experiment showed that a reduction to 750 $MJ.m^{-2}$ is realistic. This was the result of an integral approach in a modern cultivation where climate settings were adjusted weekly according to crop development. This is not possible in year-round simulations. The approach to validate the combined effects of double movable screens, forced ventilation and advanced climate control adjusted to the crop development does not allow to distinguish the contributions of the separate elements of the concept to the energy saving.

It is obvious that an intensive use of screens was realised. Screens largely contribute to reduce the energy demand. This is in accordance with the calculations of Elings et al. (2005). The combination with forced ventilation extended the possibilities to use the screens because screens can be kept closed without vapour problems. This was expected and in accordance with the research of Campen (2008), who proved that also with a double screen forced ventilation contributes to control of humidity.

Controlling humidity has its limits. In this first cropping season, the forced ventilation was used insufficiently in March (see Fig. 6, where the ventilator only started at 0.5 $g.m^{-3}$), resulting in a serious infection with Botrytis in April. By crop management and better use of the forced ventilation, the infection could be controlled fully without a clear negative effect on the production. Forced ventilation is not effective in autumn or other periods of the year when the humidity outside the greenhouse is approximately the same as within the greenhouse. The fact that forced ventilation brings dry air into the greenhouse under the crop is seen as a major advantage of this type of ventilation compared to vapour removal by opening ventilation windows above a crop. This is because the dry air first reaches the stems where Botrytis may occur. By ventilation through the roofs the outside air has already taken up moisture from the canopy before it reaches the bottom part of the greenhouse.

Energy saving reduced the temperature of the heating pipes, which might have been the reason for the slight delay in early production. This has led to a renewed discussion on the best location of the heating system. Should it be primary via the pipe-rail or would it be better to heat closer to the fruits in the canopy? Heating closer to the fruit might be preferable. Model calculations showed a small effect on harvest date for tomato grown in a closed greenhouse with temperature gradients.

Reducing the heating demand in summer will lead to a considerable reduction in the availability of CO_2 to supply in the greenhouse. Using CO_2 from industrial sources will be the only option to avoid unacceptable reduction in production.

Knowledge transfer and involvement of growers were important issues in the project. Sharing observations with growers and advisory service resulted in frequent discussions about do's and don'ts in practical application. Although results cannot be statistically analysed growers accepted the results of 1000 m^2 as reliable information. The intensive knowledge transfer contributed to the incorporation of the new approach for energy saving into practice. Results of the desk study, followed by this first experiment within the research programme "Greenhouse as a source of energy" (website www.Energiek2020.nu) under the name "The Next Generation Greenhouse Cultivation" has already led to the successful application of forced ventilation in combination with screening at 4 large tomato companies in The Netherlands.

Literature Cited

Campen, J.B. 2008. Vapour removal from the greenhouse using forced ventilation when applying a thermal screen. Acta Hort. 801:863-868.

Dieleman, J.A., Hemming, S. 2011. Energy saving: from engineering to crop management. Acta Hort. 893:65-73

Elings, A., Kempkes, F.L.K., Kaarsemaker, R.C., Ruijs, M.N.A., Braak, N.J.van der, Dueck, T.A. 2005. The energy balance and energy-saving measures in greenhouse tomato cultivation. Acta Hort. 691:67-74.

Gelder, A. de, Poot, E.H., Dieleman, J.A. and de Zwart, H.F. 2012. A concept for reduced energy demand of greenhouses: the next generation greenhouse cultivation in the Netherlands. Acta Hort. 952:539-544.

Gieling, T.H., Campen, J.B., Dieleman, J.A., Garcia, N, Janssen, H.J.J., Kempkes, F.L.K., Kromwijk, J.A.M., Raaphorst, M.G.M. 2001. Monitoring of climate variables in semi-closed greenhouse. Acta Hort. 893:1073-1080

Marcelis, L.F.M., Boogaard, H.A.G.M. van den, Meinen, E. 2000. Control of crop growth and nutrient supply by the combined use of crop models and plant sensors. In: Proc. Int. Conf. Modelling and Control in Agriculture, Horticulture and PostHarvested Processing. IFAC, p. 351-356.

Montero, J.I., van Henten, E.J., Son, J.E., Castilla, N. 2011. Greenhouse engeneering: new technologies and approachers . Acta Hort. 893: 51-63

Zwart, De, H.F. 1996. Analysing energy-saving options in greenhouse cultivation using a simulation model. Thesis Agricultural University, Wageningen.

Figures

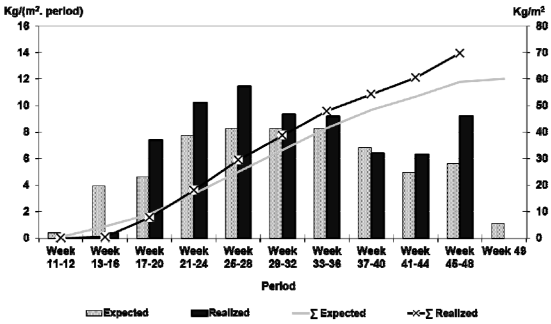

Fig. 1. Expected and realized tomato production.

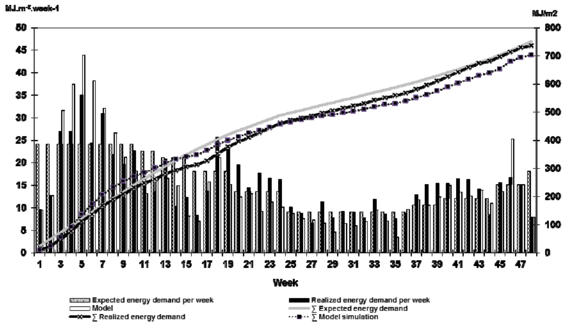

Fig. 2. Expected, simulated and realized energy demand per week and cumulated over 2009.

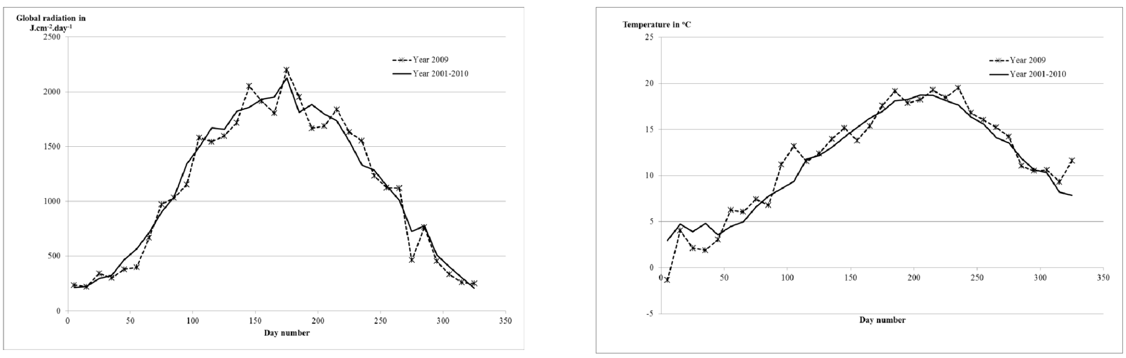

Fig. 3. Pattern of global radiation and outdoor temperature (averaged per 10 days) observed in 2009 with the climate computer and the average over 2001-2010 observed by the Royal Netherlands Meteorological Institute at a local weather station.

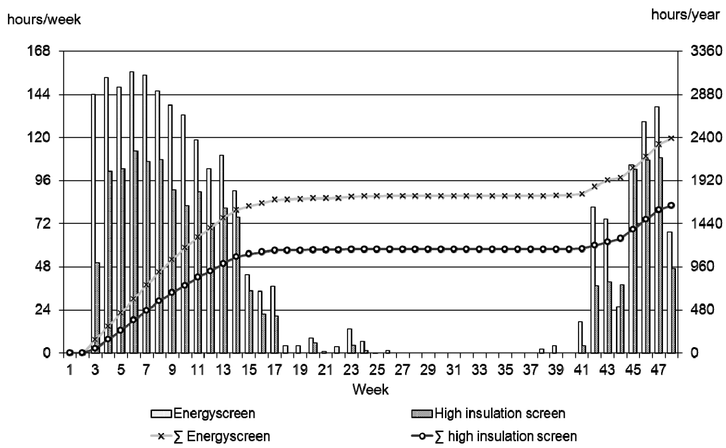

Fig. 4. The number of hours per week the screens were closed and the cumulative use of the screens in hours/year.

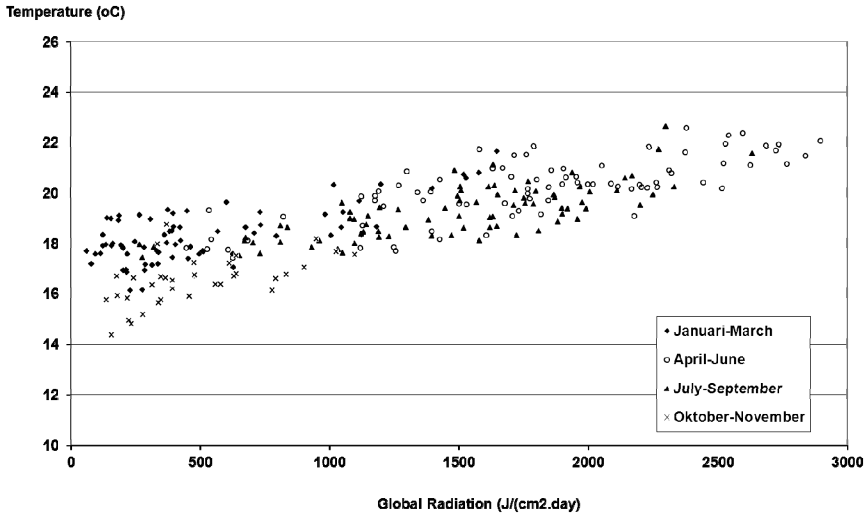

Fig. 5. Relation between daily global radiation sum and realized diurnal temperature per season.

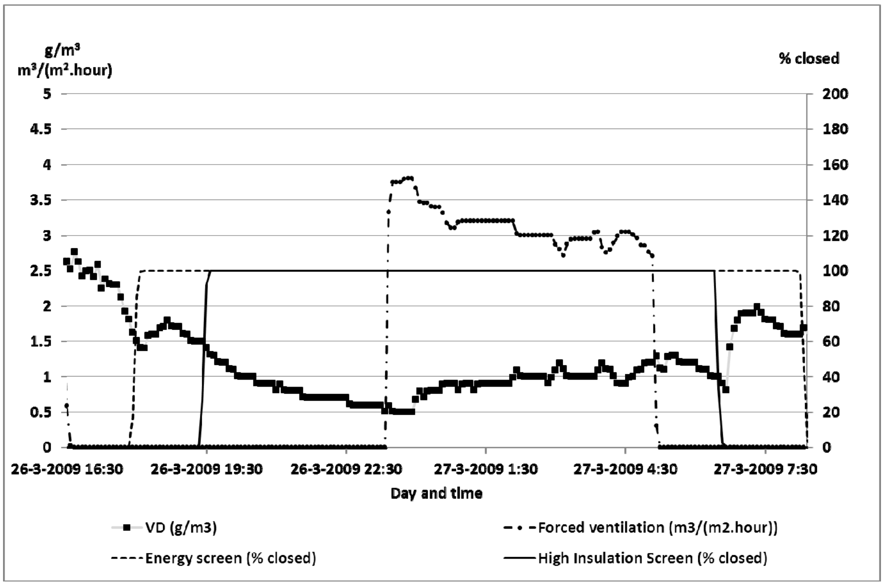

Fig. 6. Effect of screens and forced ventilation on vapour deficit.